UNICON *690*

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INTRODUCTION

The UNICON® Laser Mass Memory System currently being developed by Precision Instrument Company, as described briefly in the following pages, provides the capability of permanently recording and reproducing up to 10^{12} bits of digital data under computer control. Utilizing a new type of permanent recording process which employs a laser to vaporize minute holes in the metallic surface of a recording medium, the Laser Mass Memory System writes parallel data tracks along the length of the recording medium which is mounted on the cylindrical surface of either or both of two independent read/write drums.

In addition to the Laser Recording Unit, the Laser Mass Memory System includes a Recorder Control Unit which provides a hardware and software interface compatible with the user's computer. The Recorder Control Unit also provides for simultaneous processing of data to and from each drum in either a read or a write operation. This subsystem also controls the automatic selection of recording medium strips to or from a common strip file and the loading or unloading of a strip from either read/write drum, so that no operator action is required during the recording and reproducing of up to 10^{12} bits of data.

HISTORICAL DEVELOPMENT

The development of the Laser Mass Memory System concepts has been prompted by Precision Instrument Company's experience in the field of magnetic tape recording. A manufacturer of quality, state-of-the-art magnetic tape recorders for over a decade, Precision Instrument Company has long been aware of the inherent problems associated with the use of magnetic tape as a means for long-term storage of data, as well as a high-density data-storage medium. Since data stored for long terms on magnetic tape is subject to degradation such as print through and bit dropouts, and short-term storage density is limited by restrictions in tape coating, tape transport head resolution, and mechanical tape handling problems, it was determined that another means had to be found or developed if a truly high-density permanent data storage system were to become a reality.

The efforts began in 1961 with experimentation toward developing a record/reproduce system which would employ coherent light recording techniques through the use of single-mode coherent laser radiation in a rotating optical system for two dimensional data recording and reproduction.

The result of these efforts was the UNICON, Unidensity Coherent Light Data Processing System. The system was based on the creation and detection of diffraction-limited evaporation elements of a medium, which was first demonstrated on a quartz surface at Precision Instrument Company in October, 1963. The UNICON system used a special unidensity medium on an ordinary film base for coherent light recording in such a manner that, through incident coherent laser radiation, diffraction-limited bits of information were permanently evaporated in the recording medium in a two-dimensional pattern. Coherent light reproduction was obtained instantaneously during recording or during secondary readout by detection of the transmitted light through the opening created in the unidensity medium during recording.

The system was limited only by the wave length and power of the record/reproduce laser and provided up to two orders of magnitude higher performance in the two critical parameters of information density and frequency bandwidth than was possible with any magnetic tape recording system.

The operational principle of the UNICON system was characterized as the electro-optical signal modulation of a coherent light beam from an argon II ionic laser of TEM zero-order mode. Signal modulation occurred in the form of digital frequency, phase or pulse-width modulation. The laser beam was focused on the unidensity medium by means of two diffraction-limited objectives which were part of a rotating optical system. During the helical recording process, the image of the laser aperture was swept at high speed across the unidensity medium yielding a recording in conjunction with the high linear motion of the unidensity medium, much in the same manner as is the case in the helical recording technique used in today's wide-band instrumentation and video tape recorders.

Recent developments at Precision Instrument Company have prompted the use of the outstanding engineering talents found in the Systems Engineering Group to develop a high-density permanent laser recording system based on UNICON. Their experience was brought to bear upon the existing proven concepts of the UNICON system, and they developed the laser recording unit used as part of the Laser Mass Memory System described herein.

The Laser Mass Memory System utilizes the basic physical concepts of diffraction-limited evaporation of the rotary optics UNICON system; however, as a means of simplifying the data-tracking requirements for data reproduction while providing data records of a tenable size, the laser recording unit uses a fixed high-density recording medium mounted on a rotating drum, with recorded data being read through reflected, rather than transmitted, light.

It was found through the development of a prototype unit that this concept was not only feasible, but that it was, in fact, quite satisfactory in operation. Soon after proving through repeated demonstration that the Laser Mass Memory System was a feasible approach in meeting the ever-expanding industry requirements for a high-density permanent mass data store, efforts began in defining a control subsystem that would effectively control the Laser Recording Unit so that it could be used as a computer peripheral on-line data storage device with any of a number of large computers. This effort resulted in the definition of the Recorder Control Unit.

At this point, Precision Instrument Company began to explore the potential marketplace for such a device even more rigorously, with the result that it was determined that industry was, in fact, ready for such a device, but that the real requirement was for on-line, direct-access 10^{12}-bit memory. To accommodate this requirement, the random access strip file was added to the design, resulting in the UNICON Laser Mass Memory System described below.

SYSTEM FEATURES

Major benefits offered by the Laser Mass Memory System as a mass digital-data storage unit are summarized below:

- Permanent Storage: Data do not degrade over a period of time of the order of years.
- Compact Storage: Data are stored at a density approximately 250 to 1,000 times greater than that of digital magnetic tape.
- Unlimited Readout: Data can be repeatedly read out for long periods of time without reduction in quality or damage to the record.
- Recording Verification: Essentially error-free data records result from the simultaneous read-while-write verification capability that is unique to the laser method of permanent recording.
- Low Error Rates: The average uncorrected error rate is approximately one in 10^8 bits.
- Economical Data Storage: Recording of large quantities of data on the Laser Recording Unit and permanent storage of the data on data strips significantly decreases the cost-per-bit of recording and storage imposed by existing methods.

The salient characteristics of the Laser Mass Memory System are summarized below:

Dual Drum	Independent Read/Record
Common File	Approximately 400 data strips
File Capacity	10^{12} bits
Read and Record:	
Data Rate	4 megabits/sec
Access Time:	
Strip-to-Strip	5 seconds
Within Strip (3×10^9 bits)	200 milliseconds
Within 10^6 Field: (Approx. 16 tracks)	2 milliseconds + rotational delays
Error Rate	Less than 1 error in 10^8 bits.

UNICON

LASER MASS MEMORY SYSTEM

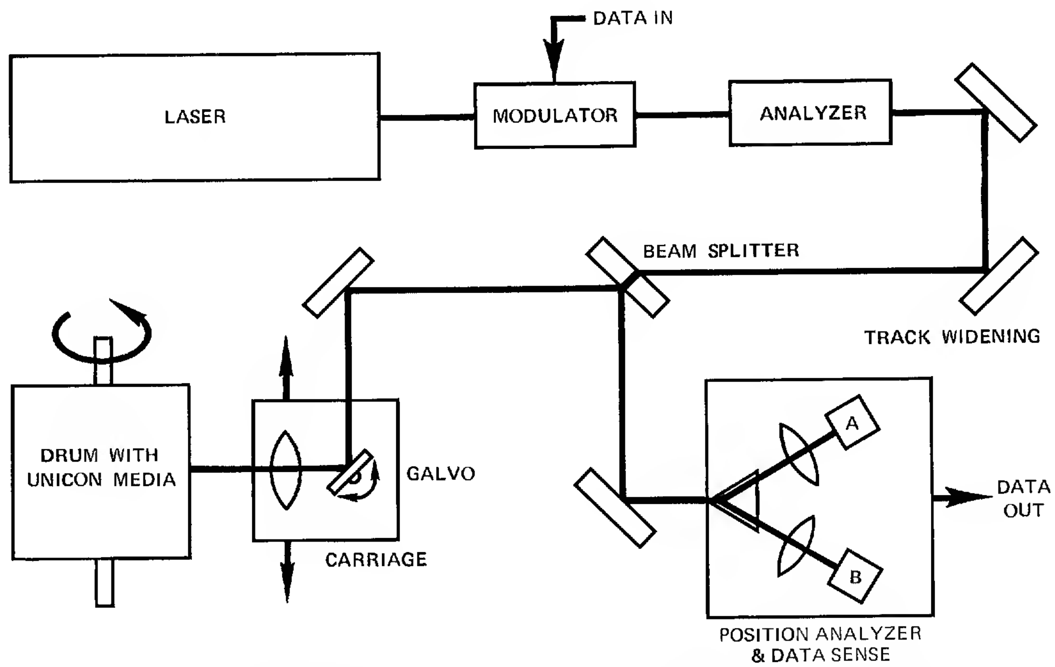
The Laser Mass Memory System is a peripheral device with respect to a large computing or data processing system. However, the Laser Mass Memory System is composed of several major elements and can be functionally described as a high-density permanent data storage system, composed of two major subsystems, the Laser Recording Unit and the Recorder Control Unit.

LASER RECORDING UNIT

The Laser Recording Unit is composed of two read/record units, each with independent simultaneous read/write capability, with provision for automatic data selection from a common 10^{12} bit mass file.

Data are recorded on data strips which are polyester sheets approximately 4.75 inches wide by 31.25 inches long by 0.007 inches thick, having a suitable metallic thin-film recording surface. The 10^{12} bit common file unit is composed of eighteen strip packs, each containing 25 data strips, with all packs securely mounted in a frame which can be readily transferred in such a manner that any selected data strip can be positioned accurately under either drum unit, and the selected strip ejected from the file in such a manner that the drum loading/unloading mechanism can operate to place the strip on the drum in a position suitable for recording or retrieval of data. Each of the eighteen strip packs are individually removable from the file unit through an access door in the Laser Recording Unit cabinet, and may be replaced by other such units for modification of the contents of the common file.

Each of the two read/record units is composed of a rotatable drum unit, together with a loading/unloading mechanism for transfer of the selected data strip to or from the common mass file to a working position on the drum surface. Adjacent to the drum, a track selection mechanism is provided for support of an optical head which directs laser light onto any



SIMPLIFIED FLOW DIAGRAM, LASER RECORDING/READING PROCESS

selected region of the data strip which has been mounted and is rotating on the drum unit. A light modulator unit, together with suitable optical elements provides control of the intensity of the laser light beam, in a manner suitable for recording of data through vaporization of minute holes in the recording medium surface of a data strip, and for illumination of recorded data tracks for reading. Additional optical elements and a data sense unit utilize the laser light reflected from a selected region of the rotating data strip for retrieval of the stored information.

RECORDER CONTROL UNIT

The Recorder Control Unit is composed of a programmed control computer and one or two word processors, which, with the assistance of properly interfaced input/output control units, will simultaneously operate and control the Laser Recording Unit, and control the bidirectional data flow of two independent I/O data streams.

The control computer is a programmable conventionally-built small scale general purpose computer with a fast cycle time, protected core memory storage, and a flexible multi-mode I/O system. The instruction set and execution times are designed to facilitate both the control applications and I/O operations necessary to maintain efficient data recording and retrieval processes.

A Word Processor is a special-purpose programmable high-speed computer employed to supervise the data flow to or from one read/record head of the Laser Recording Unit. During record mode, as a data stream is received for recording, the word processor will: (1) assemble the data, (2) encode and append a record-oriented error detecting parity check code, (3) provide temporary data buffering.

As data is transmitted out for recording, the word processor will: (1) insert timing and diagnostic patterns, at the beginning of each track, or sector, if these have not been previously recorded during strip initialization; (2) write all descriptor codes; (3) logically verify single bit recording; (4) append a verification to every word correctly written; or (5) order a word to be rerecorded if verification fails.

During the read mode, as data is retrieved from the Laser Recording Unit the word processor will: (1) provide temporary buffering for the retrieved information; (2) verify the descriptor code; (3) remove timing; (4) check word recorded validity; (5) recompute the record oriented error detection parity check; (6) perform an error detection; and (7) initiate a reread if error appears.

One or two word processor units will be included in the Recorder Control Unit, as required by system configuration. A two-drum Laser Recording Unit with capability of two simultaneous data streams will require two word processors, as well as provision for two Channel I/O units, and two Recorder I/O units. The Channel I/O interface is a multi-device control unit capable of communication with the external CPU I/O Channel in a directly programmed multiplex or burst mode. The Channel I/O interface will provide the logical capability to adapt the characteristics of the Recorder Control Unit to the standard form provided by the IBM 360/75 CPU I/O Channels, or alternatively, to be compatible to other external system CPU units. One or two independent Channel I/O interface units will be provided in the Recorder Control Unit as required by system configuration.

The File I/O Interface is a control unit capable of communication with the common file unit in the Laser Recording Unit. Communication through this channel will control the selector unit of the common file for positioning of addressed record strips into loading position under either of the two read/record drum units.

The Recorder I/O Interface is a control unit capable of communication with a read/record drum assembly in the Laser Recording Unit. Communication through this channel will control the load/unload mechanism, motor drive, carriage positioning drive, and tracking galvanometer command inputs, as well as sense status of these subsystems. A Recorder I/O Interface is required for each read/record drum assembly provided in the Laser Recording Unit.

FILE ORGANIZATION

GENERAL

Since the Laser Mass Memory System is a permanent recording device, with nondestructive read, data once written cannot be erased and rewritten as in a magnetic memory. For a large direct access file one convenient organization is that the file master index resides in memory under control of the CPU. When it is desired to delete or modify a record in the Laser Mass Memory System, the record data is pulled out to core, the data modification made, and the entire record rewritten at a new vacant location on the recording medium. The new track address is then placed in the index in place of the obsolete address, and this data item thereafter accessed at the new location in the mass store.

Where a data record has continuing transactions, which do not obsolete the remainder of the record, at the time of initially placing this record into the mass store, blank spaces may be left, and a local address stored in the index. Then when a transaction is to be added to a mass store record, this local address is read from the index, incremented by one and

returned, the mass file track and sector address read, access obtained, local address used to count down the record, and the new transaction written. This may be repeated until the local address regions initially allocated to this record are all filled. Then, either a transfer address to a new mass store track may be utilized for continuation of the record, or the procedure of completely transferring the record to a new location in the mass file may be used.

In a Laser Mass Memory System which contains more than one read/write drum the mass file may from time to time have all obsolete material deleted, by passing through the current index and rewriting only those portions of the original mass file which are currently accessible. Also, a special mark or code can be placed on any data record in the mass store to cause the readout system to ignore this data, in a manner similar to that used for read-while write data validation in which any write error causes the data to be marked as invalid, and the recording repeated. The mass file index may be placed on the data record strips themselves, though allocation of a small number of data tracks on each strip for the index associated with that strip, with only a higher-level index then residing in the CPU memory, or one or more strips may be devoted to index. Either of these procedures involve some additional access time requirements over index residing entirely in a separate memory device. For index protection, the current state of the index may be copied into the permanent mass store at frequent intervals.

The 10^{12} bit on-line mass file is composed of a number of record strips located within a mechanical selector unit in the Laser Recording Unit. Any strip may be accessed to either of two read/write drum units. It is assumed that a direct access storage system will incorporate two drums for convenience in file updating, strip copying, and minimization of access times. The contents of this on-line mass file may be modified as desired by manual insertion of a new set of data-strips into the Laser Recording Unit from off-line files of any desired size.

RECORD STRIP CONFIGURATION

The number of data record strips necessary to produce an on-line file of 10^{12} bit capacity is a function of the capacity of each individual strip. This capacity is a function of recording density, which in turn is limited by the allowable system error rate.

For the system currently being developed at Precision Instrument Company a data format utilizing bit cells four microns wide by three microns long recorded on parallel tracks separated by eight microns will be employed. Such an arrangement will provide for recording 262,000 bits on each track and 3,175 tracks per inch of medium width. As currently configured, a 3.5 inch wide area will be recorded on each data strip. This means that each strip will have a capacity of approximately 2.9 billion bits, or that a strip file containing 400 data strips will have a capacity of 1.165 trillion bits.

The selected strip capacity also may be constrained by a requirement to permit convenient addressing in terms compatible with programming for some already existing device. For example, the organization for a Laser Recording Unit recording-medium strip may be designed to simulate as nearly as possible the organization of an IBM 2314 Direct Access Storage Facility device.

In IBM cylinder terminology, the IBM 2314 device consists of eight packs, or volumes. Each

pack contains 200 cylinders, and each cylinder has 20 tracks. The packs represent drives, the cylinders represent the number of positions to which the access mechanism can move, and the tracks represent the recording-surface accessed tracks available on the 11 discs associated with each drive.

The Laser Recording Unit record strip in this example will contain 11,200 tracks divided into eight regions each representing a pack of 1,400 tracks. Each region (pack) is divided into 200 groups of 7 tracks. On each track of the record strip, the equivalent of three IBM 2314 tracks is recorded in three sectors (A, B, and C); the C sector of the seventh track is retained as a spare.

Since each sector of the record strip contains 7,294 data bytes, a cylinder contains 145,880 data bytes, a pack or disc-storage module contains 29,176,000 bytes, and the Laser Recording Unit record strip contains 233,408,000 data bytes. This data density is equivalent to the capacity of the IBM 2314, plus approximately 11.6 million bytes of spare data space. This strip capacity will be provided with a bit-cell size of four microns, allowing a bit density of 6,350 bits per inch along each data track and thus approximately 198,500 per track; a center-to-center track spacing of eight microns will provide a track density of 3,175 tracks per inch of recording-medium width. Since about 11 percent of the recorded bits will be used for clocking and control purposes, approximately 175,000 bits per track will represent the net data-recording capacity. With about 11,200 tracks recorded on each strip, the total net data capacity of the strip will be 1.96×10^9 bits or 245 million bytes. A data transfer rate of 500,000 bytes per second will be obtained at a drum rotation speed of 22.9 rps (43.7 milliseconds per revolution).

DATA FORMAT

Data is written in binary code on the recording medium in such a manner that the beam is focused onto the medium at the beginning of a series of "ones." The beam continues to vaporize the recording medium until a "zero" is to be recorded at which time the beam is "turned off" (incident radiation is reduced to the read level) by the modulator. In this manner it is possible to provide recordings which require fewer transitions from burn to no-burn (and thus less switching of the modulator) than would be required if a "punched tape" approach were taken in accomplishing the recording.

UNICON is a proprietary product of Precision Instrument Company. (U.S. Patents No. 3,314,073, 3,314,074, and 3,314,075. Other patents applied for.)

UNICON is a registered trademark. (Reg. U.S. Patent office, No. 836,688, issued Oct. 10, 1967.)

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